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# INDUSTRIAL APPLICATIONS OF TRIANGULATION TECHNIQUE

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Abstract: The aim of this paper is to introduce some examples of applications of an active triangulation technique. This technique is one of the most used methods of optical 3-D object measuring and reconstruction and has wide utilization in industry. There are mentioned some significant attributes of this technique, description of working principle, possible variants and so on. *Copyright © 2005 IFAC*

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## 1. INTRODUCTION

Nowadays the optical methods of measuring found widespread applications in industry, for example in surface inspection, inspection on tolerances and completeness, 3-D object recognition, surveillance of secured areas, robot vision, navigation and so on. For all these domains are significant to obtain three-dimensional notion (information about shape, surface, 3-D coordinates) about investigated object. Unfortunately in standard projective imaging, one dimension (usually the depth or distance information) from 3-D scenes is lost. That's the reason why the one of these main principles of computer 3-D object reconstruction has to be used (Haußecker and Geißler, 1999):

- Triangulation
- Optical Interferometry
- Time-of-Flight Measurement

The merits of optical methods are that there are usually very fast, non-contact and non-destructive. There are mostly used charge coupled device cameras (CCD) and digital image processing.

## 2. TRIANGULATION METHOD

The techniques based on triangulation are most widely used. We distinguish the following variants, which look very different, but use same principle:

- active triangulation techniques
- passive triangulation techniques
- measuring systems with theodolites
- "shape from shading" techniques
- focus techniques

### *2.1 Principle of an active triangulation method.*

An active triangulation method is most often applied in practice for its simplicity and robustness. This method is based on photogrammetric reconstruction of measured object by illumination its surface and contemporaneous scanning by CCD sensor. The principle of this technique is shown on Fig. 1. The light source, the detector and the illuminated part of measured object form a triangle. The join $b$ between light source and detector is called triangulation optical basis. The light source ray angle $\alpha$ is fixed whereas the angle on the detector side $\beta$ changes and it is defined by variable illuminated point on CCD chip. Based on the knowledge of two angles, one side of the triangle and the attributes of camera and objective (chip size and objective focal length), the distance can be determined.

According to the light source we distinguish these three variants:

- 1-D triangulation light point
- 2-D triangulation light stripe
- 3-D triangulation – light volume

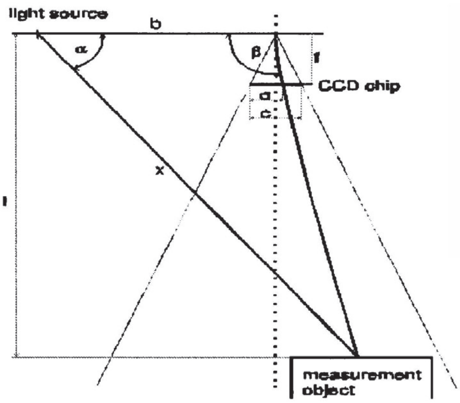


Fig. 1. Principle of the triangulation method (1-D technique).

*2.2 Formulas.*

*Mathematical description of 1-D triangulation.* If the reflected ray of the light is projected to the $n^{th}$ pixel from the total number *pxl* of pixels, than the size of the corresponding projection *a* [mm] can be calculated by formula (1) (Kalová and Lisztwan, 2005), where *c* is the chip size [mm].

$$a = \frac{c \cdot n}{pxl} \text{ [mm]}, \qquad (1)$$

The projection *a* is used to angle $\beta$ computation (*f* ... focal length [mm]).

$$\beta = actg\left(\frac{c/2 - a}{f}\right) + 90^o \text{ [°]}, \qquad (2)$$

The distance *l* can be determined due to angles $\alpha$, $\beta$ and the size of base *b*:

$$l = \frac{b \cdot \sin\alpha \cdot \sin\beta}{\sin(180^o - (\alpha + \beta))} \text{ [mm]} \qquad (3)$$

*Calibration.* These formulas are very sensitive to accuracy of inserted data. Small shortcoming on input side brings big inexactitude on output. Mathematical description for 2-D and 3-D triangulation techniques are more complicated too. That's the reason why a transformation formula obtained by calibration is usually used. The transform matrix (dimension 3x3) is used. Each constituent member represents mutual relation between image (coordinates *u*, *v*) and object space (coordinates *x*, *y*, *z*). This relation is characterizes by following equation (4).

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} t_1 & t_2 & t_3 \\ t_4 & t_5 & t_6 \\ t_7 & t_8 & t_9 \end{pmatrix} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \qquad (4)$$

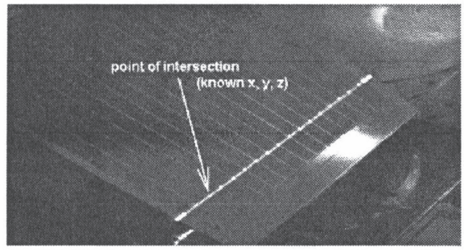


Fig. 2. Calibration object.

For matrix members ($t_1$, $t_2$, ..., $t_9$) determination is needed to make calibration by known object (known spatial coordinates of points on object, Fig. 2). Then data file with set of points in format *u*, *v*, *x*, *y*, *z* is necessary to provide. With these data the transformation matrix is established by minimisation of differences between set and computed values.

*2.3 Accuracy.*

If the investigated object is situated further to the camera and light source, the projection *a* is bigger too. This means that reflected light ray is projected to the pixel more right (according to Fig. 1). In this way, the distance of the object can be obtained just from the position of the light point in the image from the camera. The measuring accuracy and also the usability of this method depend on several parameters. The better resolution (smaller difference of measured distances of two neighbouring pixels - lesser discretisation error) can be obtained by increasing size of base *b*, camera resolution *pxl* (number of photosensitive elements) and objective focal length *f* and on the other hand by lessening chip size *c*. Fine accuracy is achieved in shorter measuring distance *l* too. Important is angle $\alpha$ too.

*2.4 Scanning process.*

If the light volume is used, the whole object can be marked en block so no scanning is required. This is a big advantage as against 1-D and 2-D techniques, when the object has to be measured step by step. By using variants with light point or stripe just one point or profile is obtained during one measuring (one image). Gauging of whole object requires several separated measuring with changed position of object or beam of light. On the other side, these variants are usually faster (linear or specifically adapted camera - see 2.7) and structurally simple (cheaper). There are advantageously used with some complementary linear or rotary movement (f. e. on production line, where the measured object moves in itself).

*2.5 Important drawbacks.*

The disadvantage of triangulation method is that due to the concavities on object the projected point, stripe or volume is not always visible and so it can be said nothing about object surface in these areas (Hlaváč and Šonka, 1992).